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A Non-Contact Type Comb Drive for the Removal of Stiction Mechanism in MEMS Switch

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***Abstract*— One of the barriers to full commercialization of complicated MEMS devices is reliableness. Stiction may be a major obstacle within the reliableness of MEMS electrical phenomenon switches. Stiction failures in microelectromechanical systems (MEMS) occur once suspended elastic members are unexpectedly falls right down to their substrates or once surface forces overcome the mechanical restoring force of a micro-structure. This paper presents the novel comb drive kind of switch. The planned switch is free from microwelding and stiction problem; successively it provides the high reliableness and long period of time. Upon application of a bias voltage, the comb drive maximizes their capacitance by increasing the overlap space between them. The switch is on and off depends on comb drive propulsion principal by the modification of capacitance between the ground line and signal lines. The proposed structure gives very low insertion loss and high isolation.**

***Index Term*- MEMS, Stiction, comb drive, micromachined, electrostatic actuator, actuation voltage, wafers.**

I. Introduction

The term MEMS refers to a collection of micro-sensors and actuators which can sense its environment and have the ability to react to changes in that environment with the use of a microcircuit control. Micro components make the system faster, more reliable, cheaper and capable of incorporating more complex functions [1].Some of the features such as Low power consumption, high RF performance, low weight, low cost, and the ability to be integrated with other electronics all make MEMS switches an attractive alternative to the conventional electronics (PIN or FET) switches. Despite of these advantages, these devices suffer from relatively slow switching speeds or high actuation voltages, ultimately making them unsuitable for use in wireless communication terminals. MEMS switches can be used in GSM mobile phone, phased array and reconfigurable aperture antennas for defense and telecommunication systems, in switching networks for satellite communications, and in single pole multi-through switches for wireless applications [2].

Despite better performance over other competing technologies such as PIN or FET switches, the commercialization of shunt capacitive RF MEMS switches is hindered by the reliability problem of RF MEMS switch. The causes of the switch failure are mainly the electrical failures such as dielectric breakdown and the mechanical failures such as capillary stiction, dielectric charging induced stiction, the buckling or broken off the bridge, and the self-actuation under high power condition [3]. There are two generalized types of switches: ohmic and capacitive. Ohmic switches make direct contacts between two electrodes while capacitive switches form metal insulator metal contacts. Both types of switches have the ability to operate more than billon of cycle without any reliability issue. Ohmic switches more often fails by stiction, whereas capacitive switches often fails due to charging of their dielectric insulators [4]. The metal to metal contacts are always forming in metal contacting switches to achieve ohmic contact between two electrodes. The capacitive switches have a thin dielectric film and an air gap between the two metallic contact surfaces. The air gap is electromechanically adjusted to achieve a capacitance change between the 'up' and 'down' state. The capacitance ratio of the downstate value to the upstate value is a key parameter for such a device; a high capacitance ratio is always desirable [5]. Among various reported reliability concerns for electrostatic capacitive MEMS switches, the dielectric charging and its resulting stiction is considered the main failure mechanism of these devices.

To rectify the problem of stiction, we have designed a noncontact- type MEMS switch. In this micro structure, the microwelding and stiction problems in the contact switches are eliminated. The proposed micro structure is designed with variable capacitance structure which does not allow direct contact or indirect contact [6]. Comb drive actuators consist of two interdigitated fingers structures, where one comb is fixed (Stator) and the other is connected to a compliant suspension (Rotor). Applying a voltage difference between the comb structures will result in a deflection of the movable comb structure by electrostatic forces. Electrostatic forces increase with decreasing gap spacing and an increasing number of comb fingers [7].

II. Problem Statement- Stiction Mechanism

Arguably stiction is one of the most important reliability challenges in contact MEMS switches. Stiction is the case in which two normally isolated surfaces that are in operational contact cannot be separated through normal operation. Capacitive switches often depend on electrostatic attraction of parallel plates. The relative motion of these plates is governed by two parameters, the "pull-in" voltage and the "pull-out" voltage. By all accounts, the pull-in voltage is a good representation of restoring force. The difference between the

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pull-in and pull-out forces is a good representation of the adhesion force. For devices to operate properly, the restoring force should always be greater than the adhesion force [8].

A consensus has developed that stiction can be caused by electrostatic attraction between charges trapped in the dielectric and the moving electrode. If the charge density is uniform, then pull down and hold down voltage both shift by the same amount. If the charge is injected from the fixed electrode and penetrates some distance into its attached dielectric, then it increases the electric field at the interface between the dielectric and the movable electrode. Thus the voltages required to operate the switch become lower. If the charge injection is large enough that the hold down voltage crosses zero, then the switch does not open at zero bias; it is stuck. This is the simplest form of stiction in dielectric switches [9].

For dielectric charging, several models have been proposed assuming that the dielectric charging arises from charges distributed throughout the dielectric material as well as the dielectric surface and the injection of charges from the electrode during ON-state. It must be pointed out that the deposited insulating films, typically Si3N4, contain a large density of traps associated with dangling bonds. These traps are amphoteric nature, so they can be negatively or positively charged [10]. Silicon dioxide has a lower trap density than silicon nitride, which implies that devices made with silicon dioxide dielectric layers should be less prone to charge trapping, i.e. longer lifetime. PECVD silicon dioxide, however, has a lower dielectric constant, 4.1–4.2, when compared to PECVD silicon nitride, 6–9, which leads to a decrease in the down-state capacitance. An ideal dielectric layer would possess both a high dielectric constant and a low trap density [11].

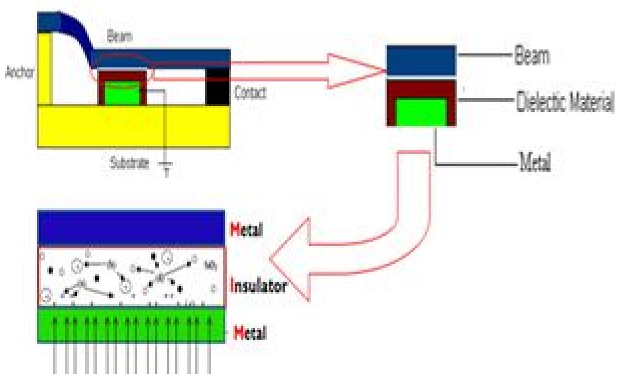

Figure 1. Beam remains in a down position even after removal of voltage and respective MIM structure. MIM structure of MEMS switch and the charge transport from negative electrode towards positive electrode. Some of the electrons are trapped inside the traps in the dielectric

Dielectric material has a trap due to presence of impurities and defect causes during the fabrication. The fig 1 shows that electrons are migrated inside the dielectric where the electrons are injected in the silicon nitride from negative electrode and the electrons are transported towards the positive electrode. In metal insulator metal structure when voltage is applied to either of the electrode, charge is being injected inside the dielectric. The injected electrons will soon be captured by traps forming a trapped space charge. In general, the trapped electrons are distributed between two electrodes [12].

In our design approach, we use comb drive actuators switch which remove the true cause of stiction i.e. dielectric charging. This structure remains the submicron gap between two electrodes when the actuation voltage applied to the comb drive actuator. This structure removes the stiction problem from the MEMS switch. This solution should be effective if the actual cause of stiction is dielectric charging.

III. Design And Working Of A Comb Drive Switch

The designed switch is a capacitive shunt type work on the principal of change of capacitance between the signal line and ground lines. The comb-drive electrodes are composed of a movable membrane and the two fixed electrodes positioned on both sides of the movable membrane. When an electrostatic potential is applied between the membrane and the fixed comb electrodes, the attractive electrostatic force pulls the membrane up from the down position (on-state) to the up position (off-state) [13]. Table 1 shows the process steps required during the designing of a micro actuator.

Table I. Process Steps Of Comb Drive Switch

umber	Step Name	Layer Name	Material Name	Thickness	Mask Name	Photoresist	Depth	Mask Offset	Sidewall Angle
0	Substrate	Substrate	SILICON	5	SubstrateMask				
1	Thermal Oxidation	Oxidation	SI3N4	0.5					
2	Evaporation	fixed_strc	ALUMINUM	2					
3	Generic Wet Etch				fixed_strc	+	2	0	0
4	Planar Fill	sacrificial layer	PSG	2					
5	Generic Wet Etch				sacrificial	-	2	0	0
6	Evaporation	Moving_ele	ALUMINUM	2					
7	Generic Wet Etch				moving_ele	+	2	0	0
8	Delete		PSG						

Initially the wafer is defined as "Step 0". The wafer is of silicon with a width of 5 um. The mask name defines the mask which is used to etch the layer according to need. Silicon Nitride is used as isolation between substrate and device structure having the thickness of 0.5 um. The step 2 uses layer of aluminum for the comb drive footings and will elevate the device 2um from the wafer surface. The removal of aluminum except the footings (anchors) is done by etching process. The areas of aluminum that were etched in the previous step are filled by sacrificial layer (PSG). PSG that was deposited on top of the anchors so that the surface is flat and ready for the structure to be built on top is removed by etching technique. The structure of comb drive is made up of aluminum hence again etching technique is used to etch away all the aluminum except the device structure. In the last step sacrificial layer removed to form the floating geometry [14].Fig. 2 gives the structure of an electrostatic

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comb drive actuator switch. The dimensions of a switch are calculated from the equation (1).

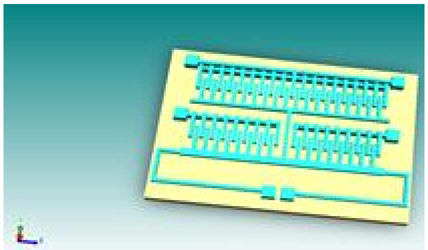

Figure 2.3D view of comb drive switch

$$I = a \times d^{3/2} \qquad (1)$$

Where I = current in ampere, d = diameter of the wire in inches, a = constant that depends on the material, a = 7585 considering aluminum as the material. The fusing current determine by the above equation which gives the dimension of the switch [15].

The electrostatic actuator is 70 um wide and 98 um in lengths. The combs and signal line of an actuator is 1.5 um wide and 2 um thick. The gap between fixed and movable comb is 5um. The proposed system is designed for carrying 5ma of a current. The moveable plate is suspended by folded beams attached to the anchors. The comb drives are used for actuation, with one side attached to the moveable plate and the other side anchored. When a voltage is applied across the two sides of the comb drive, electrostatic forces are generated and drive the movable plate in the Y-direction. As shown in Fig. 3, the switch consists of a transmission line and variable capacitors. In the ON state, the variable capacitors are not actuated and the input signal passes through the transmission line. In the OFF state, the capacitance of the actuated capacitors is changed and it prevents the signal from reaching the output port. It is to be noted that there are small air gaps between the capacitors even in the OFF state. Therefore, the capacitors do not touch each other. Thus, the proposed switch is free from the stiction and microwelding problems of a contact-type switch [16].

IV. Result

The figure 4 shows the movement of comb drive actuator. The colour discrimination shows the magnitude of displacement. Red colour shows the maximum displacement whereas blue colour shows minimum displacement of structure. After the application of maximum voltage, there is an electrostatic force of attraction which causes the movable combs moves toward the fixed combs. The movement of the combs defines the ON and OFF state of switch.

The table II and figure 5 shown below gives the tabular as well as graphical form of the combs displacement against force applied. The graph shows the maximum node displacement is in Z plane rather than X and Y plane, which shows the submicron displacement of combs in a single plane. This uniplaner directional movement provides a high precision switching of a switch.

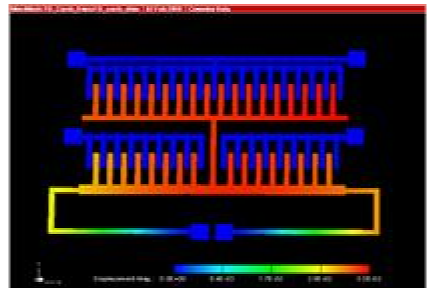

Figure 4a.Mechanical movement of switch in ON State

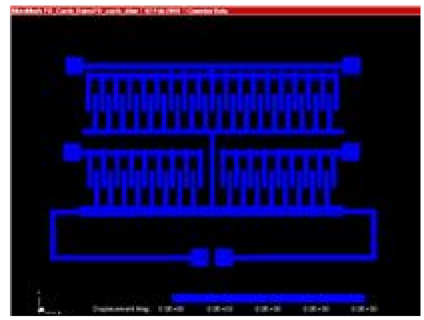

Figure 4b.Mechanical movement of switch in OFF state

Table II. Applied Pressure And Displacement Table

Step No.	Force Applied	Node Displacement Maximum
Step 1	0.001N	0.02359499 µm
Step 2	0.002 N	0.04715729 µm
Step 3	0.003 N	0.07068287 µm
Step 4	0.004 N	0.09417668 µm
Step 5	0.005 N	0.1176375 µm
Step 6	0.006 N	0.1410655 µm
Step 7	0.007 N	0.1644609 µm
Step 8	0.008 N	0.1878241 µm
Step 9	0.009 N	0.2111554 µm
Step 10	0.01 N	0.2344549 µm

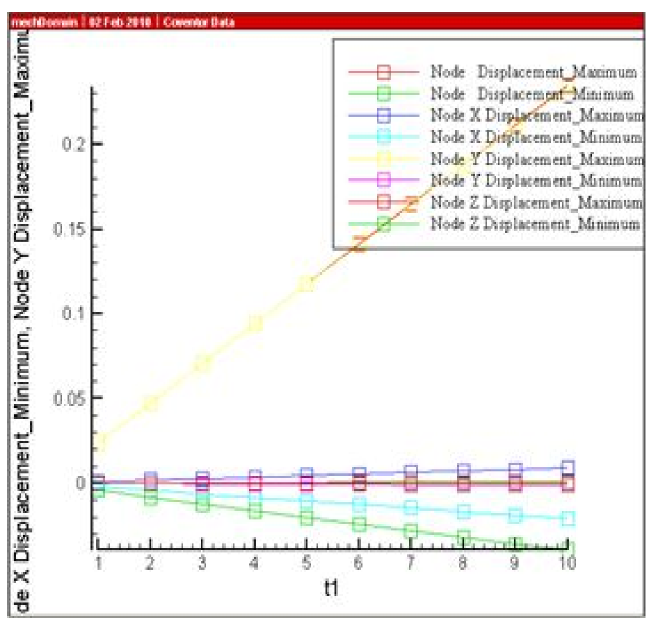

Figure5. Applied Pressure and displacement graph

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In following figure 6a and 6b, flow of signal is shown in ON and OFF condition. During the ON state of a switch, the actuation voltage is not applied on an actuator and the signal is flowing from input port to output port directly, which is shown by the red color in the entire switch line. When the actuation voltage is applied actuators are actuated then the switch is in OFF state. Here the actuators are actuated by the application of DC voltage and the input signal is DC signal. When actuators are actuated then the distance between the electrodes reduces, which gives a high impedance path in the signal line.

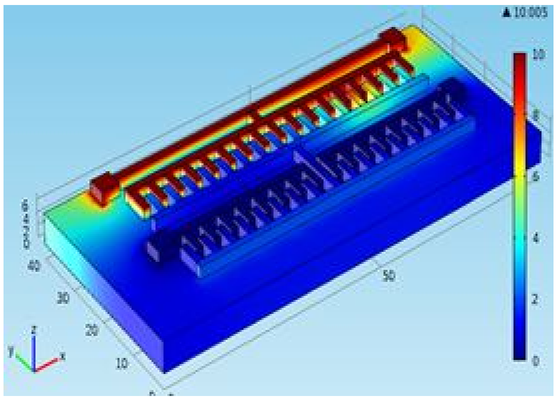

Figure 6a.ON State

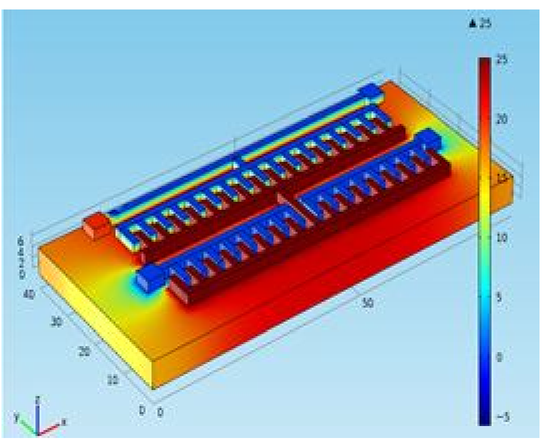

Figure 6b.OFF State

The fig. 7 a & b shown below gives graphical representation of insertion and isolation loss of a switch. During On state of switch, impedance of a signal line is very low which allow the same voltage as that of input port to the output port. This graph shows the insertion loss of the switch during on state is very low near to zero. During off state of the switch, the signal line has high impedance path which isolate output port from the input port. The capacitive coupling switch has isolation losses due to their capacitive nature.

Conclusions

The designed switch works on the principal electrostatic force of attraction, change in capacitance between fixed and movable combs. The proposed approach used for the design of the removal of stiction mechanism to improves the life time of RF MEMS switch. This switch is having high actuation voltage and low isolation between input and output and can be minimized by designing more finer and compact device.

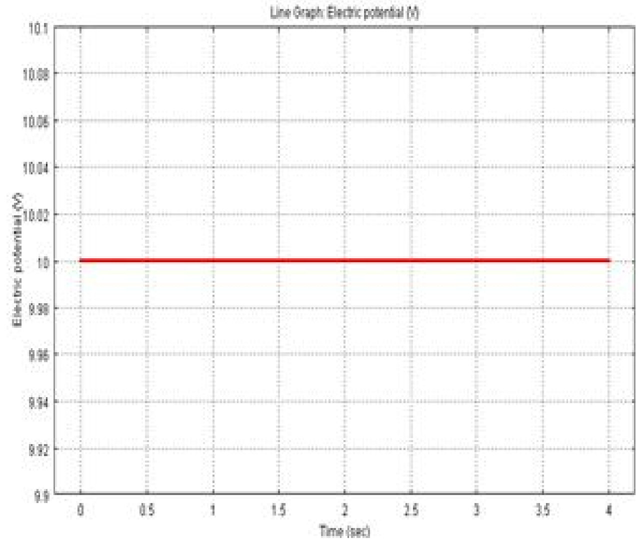

Figure 7a.ON State

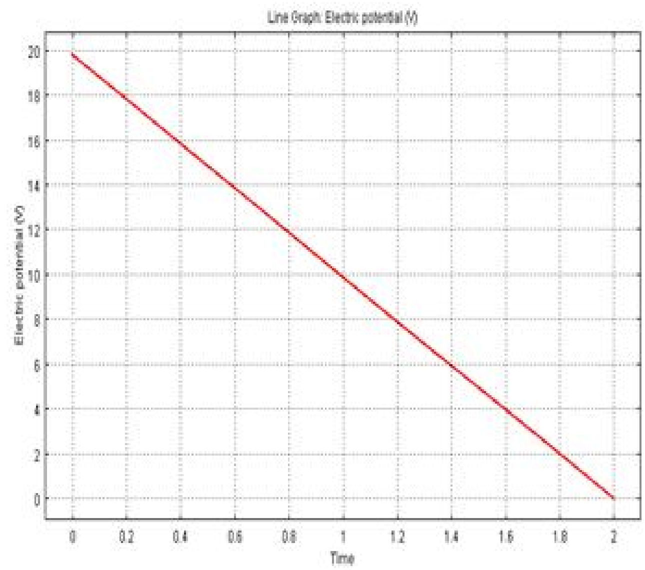

Figure 7b.OFF State

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